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Spreadsheet Model for Computing PM_{10} Impacts from Unpaved Road Travel in Pinal County, Arizona

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Introduction

The western portion of Pinal County is extensively dedicated to agricultural production. Due to its rural nature with low traffic volumes, many of the local public roads in this area are unpaved. Because of rising home prices in neighboring Maricopa County, new residential construction is beginning to proliferate in portions of the agricultural district proximate to freeway access. The juxtaposition of new residential development to existing unpaved roads is raising concerns about air quality impacts from these roads on new residents.

Annually, the Pinal County Public Works Department paves a limited number of unpaved road segments to reduce maintenance costs and to respond to concerns about dust impacts. In the process of selecting road segments for paving, the Public Works Department solicits recommendations from the Pinal County Air Quality Control District (PCAQCD). In the past, PCAQCD has responded by identifying unpaved road segments that were the subject of dust complaints filed with the agency. PCAQCD desires to use a more objective tool for prioritizing unpaved roads for paving.

In responding to this need, Sierra Research (Sierra) developed a spreadsheet modeling tool to assist PCAQCD in prioritizing unpaved road segments for recommended paving within a study area consisting of the agricultural district. The modeling tool design was outlined in a revised proposal submitted by DKS Associates to the Arizona Department of Transportation on October 13, 2004. A description of the modeling tool and instructions for use are contained in this report, together with a summary of cost-effectiveness data applicable to other means of treating unpaved road segments to reduce PM_{10} emissions.

Methodology Development

Estimates of downwind impacts from unpaved road travel emissions are best determined, within the limits of the project budget, through the use of dispersion modeling. Other, more simplistic, computational approaches are less accurate, and ambient monitoring approaches that would be more accurate are too costly. The dispersion modeling approach has the ability to couple site-specific emission rates, meteorology, and geography to produce impact estimates that are sufficiently accurate to be used in the comparison of different road segments for paving prioritization. While this approach will produce impact estimates that are accurate only within a factor of two to measured impacts,[1] this tool is not proposed to be used to determine compliance with air quality

[1] Reliability and Adequacy of Air Quality Dispersion Models, GAO/RCED-88-192, U.S. General Accounting Office, August 1988.

standards, but rather to serve as a screening tool in assessing comparative impacts from actual or projected traffic levels on selected road segments.

The existence of locally recorded meteorological data in the agricultural district of Pinal County enhances the accuracy of dispersion modeling as a tool for estimating unpaved road impacts. PCAQCD has recorded and archived meteorological data sufficient to serve modeling needs at three locations in this district: Cowtown, Casa Grande, and Eleven-Mile Corner. Analysis of the windroses from these three sites indicates similar wind patterns, with prevailing winds blowing from the west and east.

The prevalent alignment of unpaved roads along section lines in the agricultural district results in most unpaved roads running either due east-west or north-south. This factor simplified the number of dispersion modeling runs that were conducted to assess impacts for any individual road segment. In the design of this screening tool, we assumed that all roads of interest to PCAQCD were aligned in these two directions, which allowed us to limit the number of modeling runs needed to characterize dispersion patterns downwind of unpaved roads.

In the use of a screening tool, PCAQCD expressed interest in being able to evaluate PM_{10} impacts at varying distances downwind of unpaved road segments. This flexibility is needed to tailor the modeling analysis to actual or proposed juxtapositions of residential or workplace facilities and specific unpaved road segments. To avoid the need to run the dispersion model for each road segment to be studied, we conducted model runs for east-west and north-south road segments using each of the three meteorological databases developed by PCAQCD and unit emission rates. To facilitate use of the modeling results in evaluating impacts at variable distances, we used a curvefitting program to fit the modeling output to a mathematical equation that could be entered into the spreadsheet. The use of a mathematical equation to represent the modeling results will allow the user of the spreadsheet tool to enter the specific separation distance between a road segment and a selected receptor and compute the dilution factor that would be predicted by the dispersion model at that distance.

The spreadsheet modeling tool is designed to be interactive, relying on user selection of several key variables that serve as the basis for emission calculation and downwind impact assessment. By using a spreadsheet as the platform for calculations, the model will respond instantaneously to data input and change. Error protection routines are built into the spreadsheet to report unacceptable data entries including entries that are out of range.

The PM_{10} impacts downwind of an unpaved road are dependent upon the emission rate of the road segment, the meteorology of the area surrounding the road segment, and the separation distance between the receptor of interest and the downwind edge of the road segment. For this model, the emission rate of the road segment is calculated as the product of an emission factor, in units of pounds of emission per vehicle mile traveled (lb/VMT), and the daily traffic rate, in units of vehicles passing a single point on the road per day, which is also referred to as average daily traffic (ADT). The meteorology of western Pinal County is represented in the model by the hourly measurements of vital weather parameters recorded at three stations distributed across the central agricultural zone. The separation distance between road edge and receptor is a user input that can be entered in units of feet or meters in the spreadsheet model.

The emission factor for vehicle travel on unpaved roads derives from an emission equation published by the U.S. Environmental Protection Agency (EPA). This equation uses the silt (-200 mesh screen) content of loose surface soil, the surface soil moisture content, and the vehicle speed as independent variables. Data for each of these three variables were collected on five unpaved road segments in the western portion of Pinal County for use in this model. The model user can select one of these five road segments to represent the road segment of interest on the basis of similar soil type. The discussion of soil types is presented later under Emission Factor Development and Modeling Tool Use.

The meteorological database for use in the modeling analysis is a user option in the spreadsheet model. Three datasets collected by PCAQCD are available for use under this option: Cowtown, Casa Grande, and Eleven Mile Corner. Cowtown and Eleven Mile Corner represent the western and eastern thirds, respectively, of the agricultural district, while Casa Grande represents the middle portion of the study area covered by the modeling tool. The prevailing wind directions in this area are generally east and west due to jet stream flows and the east-west orientation of the agricultural district bounded by mountain ranges to the south and north. Due to these factors, meteorological conditions are assumed to be similar within each of the three longitudinally divided portions of the study area.

The downwind impacts of PM_{10} emissions from unpaved roads were evaluated using plume dispersion modeling. The modeling was performed using the CAL3QHCR model that is specifically designed to model emission dispersion from road segments. CAL3QHCR is a line source dispersion model selected by EPA as the recommended model to use in predicting inert pollutant concentrations from motor vehicles adjacent to roadway links and intersections. The model contains the CALINE3 dispersion model and uses hourly-averaged real meteorological data.

Emission Factor Development

The emission equations for unpaved road travel developed by EPA are published in AP-42.[2] The equation used in this analysis is designed to estimate particulate matter emissions from light-duty vehicle travel on unpaved roads. This equation has the following form:

$$E = [(k)(s/12)^a(S/30)^d/(M/0.5)^c - C][(365 - P)/365]$$

where: E = particulate matter emission rate, pound per vehicle miles traveled (lb/VMT)

k = particulate size factor (dimensionless)

[2] Compilation of Air Pollutant Emission Factors, AP-42, Volume 1: Stationary and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.

  = 1.8 for PM_{10}
s = surface material silt content (%)
S = mean vehicle speed, miles per hour (mph)
M = surface material moisture content (%)
a = empirical constant
  = 1.0 for PM_{10}
c = empirical constant
  = 0.2 for PM_{10}
d = empirical constant
  = 0.5 for PM_{10}
C = PM_{10} emissions from vehicle exhaust, brake wear, and tire wear (lb/VMT)
P = number of precipitation days per year on which 0.01 inches or more rain falls (days/yr)

The three variables in this equation—silt content, moisture content, and vehicle speed—vary significantly from one unpaved road to another. Because of this variability, measurements of these parameters were made on representative roads in the agricultural district to increase the accuracy of the spreadsheet model.

The unpaved roads in the agricultural district are constructed of native material. As a result, the silt content of the roadbed soil is similar to that of the surrounding soil. To evaluate the variability of silt content in soils within the agricultural district, a soils map prepared by the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) was obtained and reviewed.[3] The general soil map contained in this reference is presented in Figure 1.

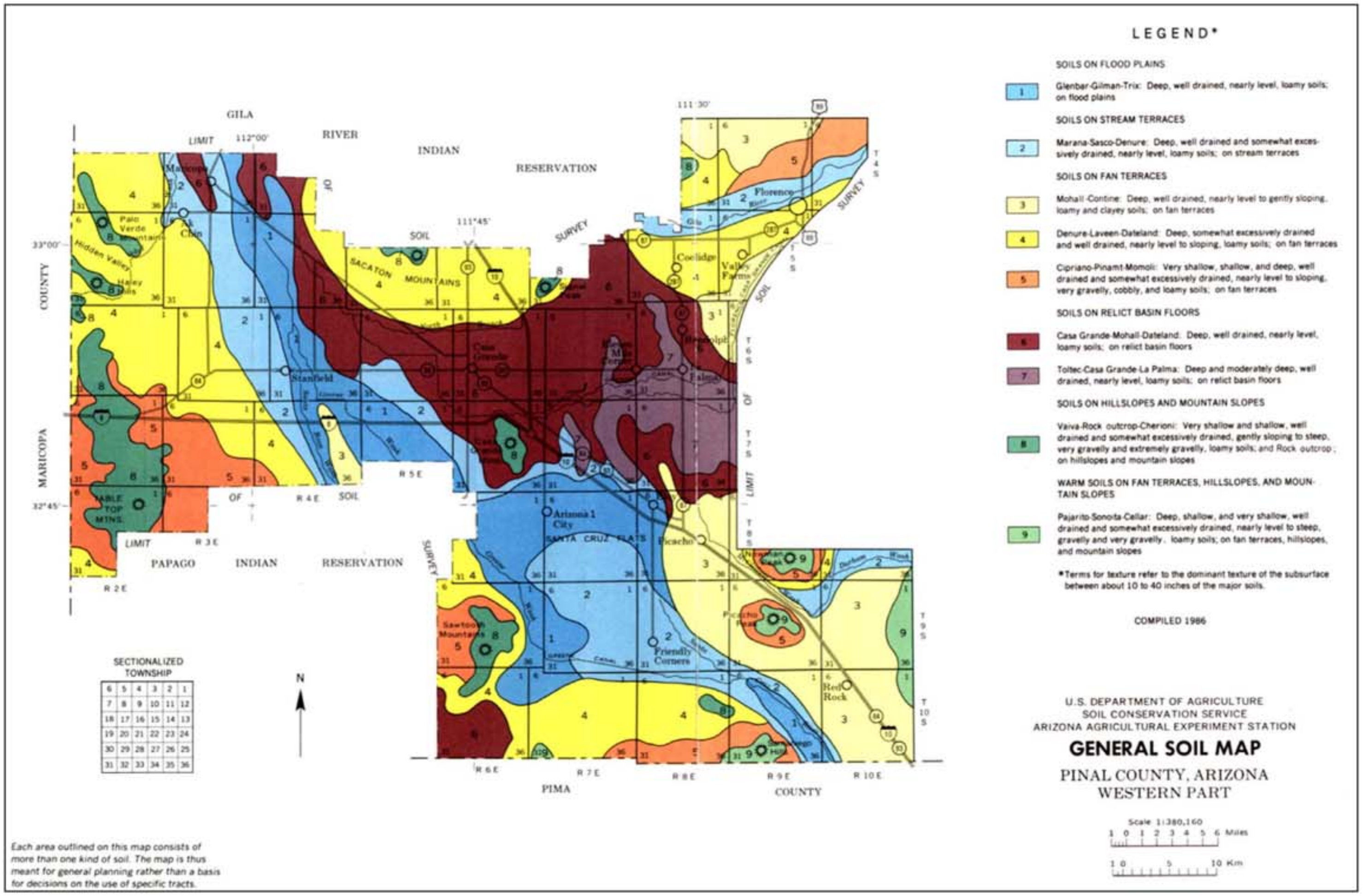
The NRCS soil map indicates that five general soil map units cover the agricultural district. These units are differentiated by the hydrologic and geologic areas in which they are found. These areas include floodplains, stream terraces, fan terraces, and relic basin floors. The names of the soil units and the areas in which they are found are listed in Table 1. The numbers in parentheses represent the numerical designation assigned by NRCS to soil units for purposes of identification on the soil map.

Table 1
Geological Locations and Names of Western Pinal County General Soil Map Units

Geological Location	General Soil Map Unit
Flood Plains	Glenbar-Gilman-Trix (1)
Stream Terraces	Marana-Sasco-Denure (2)
Fan Terraces	Denure-Laveen-Dateland (4)
Relic Basin Floors	Casa Grande-Mohall-Dateland (6)
	Toltec-Casa Grande-La Palma (7)

[3] Soil Survey of Pinal County, Arizona, Western Part, U.S. Department of Agriculture Soil Conservation Service, November 1991.

Figure 1
Western Pinal County General Soil Map



Within each of these major soil map units are located several specific soil types. The NRCS soil map book reports agricultural silt content[4] and wind erodability, among other characteristics, for each specific soil type found in the agricultural district. Within some major soil map units, the agricultural silt contents are relatively uniform, and for other map units the silt contents vary dramatically. Sierra, working with PCAQCD, identified the predominant soil types in each major soil map unit. PCAQCD, working with the Pinal County Public Works Department, identified one well-traveled unpaved road segment in a predominant soil type in each major soil map unit. The rationale for locating the unpaved road sampling site in a predominant soil type within each major soil map unit was to conduct sampling at a site that was most representative of soils throughout the major soil map unit. A list of these predominant soil types, together with data on agricultural silt content and wind erodability, underlying each selected unpaved road segment is presented in Table 2. A map showing the locations of the unpaved road segments selected for surface soil sampling is shown in Figure 2.

Table 2
Characteristics of Soils Underlying Selected Unpaved Road Segments

Selected Unpaved Road	Predominant Soil Type	Agricultural Silt Content	Wind Erodability*
Alsdorf Road	Casa Grande (4)	70% - 80%	5
Amarillo Valley Road	Dateland	25% - 35%	3
Curry Road	Casa Grande (3)	30% - 40%	3
Peters Road	Gadsden	80% - 90%	8
White & Parker Road	Trix	70% - 80%	4

*The wind erodibility scale varies from 1 (extremely erodible) to 8 (not subject to wind erosion).

At each of the selected unpaved road segments, samples of loose surface soil were collected by PCAQCD staff in early June 2005 in conformance with EPA sampling protocols.[5] At stations located 0.5 miles apart over a two-mile section of unpaved road, all of the loose surface material was collected from within one-foot-wide strips running perpendicular to the road centerline. The loose material was collected with a whisk broom and dust pan and deposited into a lined plastic bucket. Samples from each of the five strips in a two-mile section were combined in the bucket, the plastic bag/liner was taped closed, and the cover on the bucket was sealed with duct tape. The buckets were labeled by road name, date, and sample collector, and shipped within 24 hours of collection via UPS to Professional Service Industries, Inc. (PSI), a soils laboratory in Tempe, Arizona.

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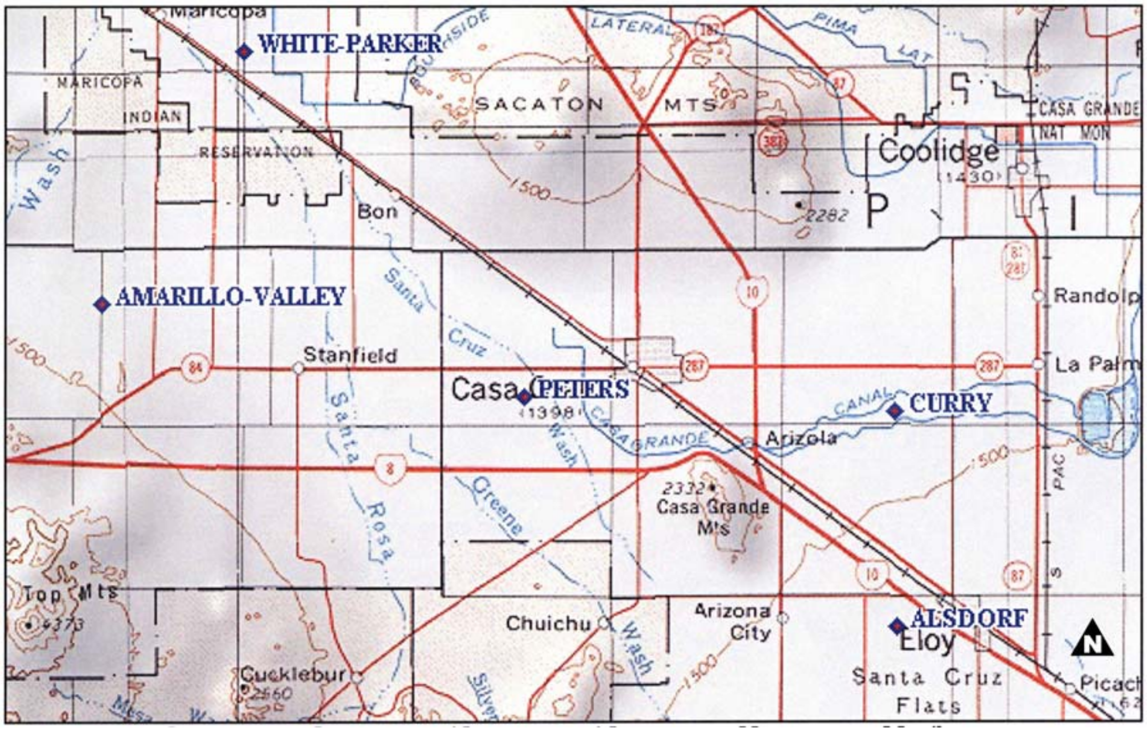
[4] Agricultural silt content differs generically from unpaved road silt content (as used in emissions analyses) as agricultural silt content is measured by a wet sieve analysis method that allows soil clumps to be broken down into individual soil particles during the screening process, while unpaved road silt content is measured by a dry sieve analysis method that leaves soil clumps intact. As a result, silt contents reported in the agricultural context are generally higher than those reported in the air pollution context, even for the same soil type.

[5] Appendix C-1, Compilation of Air Pollutant Emission Factors, Volume 1, AP-42, U.S. Environmental Protection Agency, January 1995.

Figure 2
Locations of Unpaved Road Traffic Count and Soil Sampling Sites



PSI performed sieve and moisture content analyses on the shipped samples. For the first two samples collected (Alsdorf Road and Curry Road), these analyses were conducted within about one week of receipt by the laboratory. Because of personnel changes at the laboratory, however, the second set of samples collected (Amarillo Valley Road, Peters Road, and White & Parker Road) was not analyzed until about three weeks after receipt by PSI. Although the delay in analysis of the second set of samples could have allowed moisture in the soil to evaporate, the moisture contents of soil samples at the time of collection were undoubtedly very low, and the reported measurements indicate that moisture contents of the second set of samples were equivalent to or greater than those of the first set. For these reasons, we conclude that the delay in performing moisture content analyses of the second set of soil samples did not significantly affect the analytical results. The silt and moisture contents reported for each sample are listed in Table 2.

Table 2 **Unpaved Road Surface Soil Silt and Moisture Content**		
Unpaved Road	Silt Content	Moisture Content
Alsdorf Road	2.60%	0.097%
Amarillo Valley Road	7.40%	0.106%
Curry Road	4.20%	0.154%
Peters Road	7.10%	0.306%
White & Parker Road	5.90%	0.477%

As the EPA emission factor equation for unpaved road travel also includes average vehicle speed as a variable, data on vehicle speeds were collected through the use of traffic counters. Traffic Research and Analysis, Inc. (TRA) of Phoenix, Arizona installed dual tube counters on each of the five unpaved road segments in late May 2005. Each of the counters was left in place for seven days except for the counter on Amarillo Valley Road. Due to a communication gap, the Pinal County Public Works Department graded the portion of this road where the counter was located, causing the counter to cease operation after four days. After being repaired, the counter completed a seven-day traffic count in the following week. The average vehicle speeds and average daily traffic counts for each unpaved road segment are presented in Table 3.

Table 3 **Average Vehicle Speeds and Average Daily Traffic Counts**		
Unpaved Road	Average Vehicle Speed (mph)	Average Daily Traffic Count
Alsdorf Road	42.8	153
Amarillo Valley Road	40.7	174
Curry Road	40.5	646
Peters Road	34.1	252
White & Parker Road	40.5	118

Two other factors that are constants in the EPA equation, for the purpose of this spreadsheet tool, were derived from EPA estimates and local meteorological data. The factor "C" in the EPA equation represents PM_{10} emissions from vehicle travel that are not generated by travel over unpaved roads. These emissions include particulate matter emissions from the vehicle exhaust pipe, brake wear particles, and tire wear particles. Data reported in the EPA MOBILE6.2 mobile source emission factor model lists the total of these emissions for the average light duty vehicle to be 0.00016 pounds of PM_{10} per vehicle mile traveled. This factor is subtracted from the total emissions reported by roadside testing to isolate the contribution made by travel over unpaved soil surfaces.

The factor "P" in the EPA equation represents the number of days per year when rainfall reduces unpaved road travel emissions to zero. Other research referenced in AP-42 indicates that this situation occurs on any day in which 0.01 inches or more of precipitation occurs. From longterm rainfall data collected at Stanfield and Casa Grande, as tabulated on a website maintained for the National Oceanographic and Atmospheric Administration by the Desert Research Institute,[6] the annual average number of precipitation days in the agricultural district is 30 days per year. The precipitation day adjustment factor is used to adjust annual average emission factors only. The maximum 24-hour PM_{10} impacts are assumed to occur on a day with no measurable rainfall.

After entering the appropriate constants, the emission factor for each unpaved road segment studied was calculated by inserting the measured values of silt content, moisture content, and average vehicle speed into the EPA equation. The results of these calculations are presented in Table 4.

Table 4
Unpaved Road Travel Emission Factor

Unpaved Road	PM_{10} Emission Factor (lb/VMT)	
	Annual Average	Max. 24-Hour
Alsdorf Road	0.593	0.647
Amarillo Valley Road	1.341	1.247
Curry Road	0.850	1.461
Peters Road	1.144	1.038
White & Parker Road	0.952	0.926

Dispersion Modeling Analysis

For the purpose of estimating the downwind PM_{10} impacts from unpaved road travel in Pinal County, we selected the CAL3QHCR dispersion model. CAL3QHCR is a line source dispersion model selected by EPA as the recommended model to use in predicting inert pollutant concentrations from motor vehicles adjacent to roadway links and intersections. The model contains the CALINE3 dispersion model and uses hourly-averaged real meteorological data. CALINE3-based dispersion models are uniquely designed to emulate the turbulent plume mixing that occurs in vehicle wakes prior to plumes being transported downwind by local wind currents.

Because of the need for simplicity and the budget for this project did not allow for the incorporation of the CAL3QHCR model into the spreadsheet, the model was run using

[6] Average Number of Days With Measurable Precipitation, Arizona, Western Regional Climate Center, NOAA and DRI, http://www.wrcc.dri.edu/htmlfiles/az/az.01.html, accessed on August 22, 2005

unit inputs and the results were incorporated into the spreadsheet to account for plume dispersion. The CAL3QHCR model relies on inputs of emission rate, roadway and receptor configuration, and meteorology. For the development of the spreadsheet tool, the model runs were conducted at unit average emission rates (1.0 gram per second per mile of road) in order to standardize the model results. Because the distribution of traffic on each monitored unpaved road followed a typical diurnal pattern, the traffic rates in the modeling input files were adjusted to follow the same pattern. The traffic distribution pattern for each monitored unpaved road was computed for each hour of the day as the sum of vehicle counts for that hour over the seven-day monitoring period divided by the total vehicle count for the week. The hourly fractions for all monitored roads combined were computed by weighting the hourly fractions for each road by the total vehicle count for that road and hour, summing these products together, and then dividing by the total vehicles counted on all roads and all days in that hour of the day. These resulting composite hourly fractions were then multiplied by an arbitrarily selected 1,000 vehicle per day total count to determine hourly vehicle counts for the modeling under each meteorological dataset.

The roadway sections that were modeled were configured to be 1.0 mile long and 24 feet wide. The average roadway width was estimated from field observation in Pinal County to consist of two 12-foot lanes. Two different road orientations were modeled – one with an east-west centerline and the other with a north-south centerline. Receptor locations were set at 25, 50, 100, 150, 200, 300, 400, and 500 meters from the downwind road edge on each side of the road.

Model runs were performed using each of the three meteorological databases. Two the databases, from Casa Grande (2004) and Eleven Mile Corner (2003), covered one full year each. The meteorological data collected at the Cowtown (2004) site, however, were missing 66 days of data between June 23 and August 27, 2004, due to instrument malfunction. In an attempt to determine whether the loss of data for this period would significantly influence the adequacy of the remaining data to provide representative results for annual and maximum 24-hour downwind PM_{10} impacts, we compared the PM_{10} modeling results from use of the 2004 Casa Grande meteorological database to use of the same database minus data for the June 23 to August 27 period. The modeling results for each of the maximum 24-hour averages were identical, and the results for the annual averages differed by less than 5.4% on average and by less than 10.0% for any single receptor point. The meteorological dataset containing the gap produced slightly higher annual averages to the west of north-south roads and to the south of east-west roads, and slightly lower annual averages to the east and north of modeled road segments. On this basis, we accepted the 2004 Cowtown meteorological database as being representative for use in assessing annual and maximum 24-hour PM_{10} impacts.

The CAL3QHCR modeling runs were conducted to estimate downwind impacts at regular intervals from 25 meters to 500 meters on each side of each road segment evaluated. Upon run completion, the impacts reported along each line of receptors by CAL3QHCR were processed through a curvefitting program.[7] The curvefitting program is designed to fit the modeled impact data to 23 different equation types and report the

[7] Curvefit, Version 2.11-B, Thomas S. Cox, July 1988.

correlation coefficient (r^2) for each type. Twenty-four sets of model output data were processed in this manner. The sets are combinations of the 3 meteorological datasets, the 2 roadway orientations, the 2 directions from each roadway segment in which receptors were positioned, and the 2 PM_{10} averaging periods (annual and maximum 24-hour) that serve as the basis for the national ambient air quality standards. Abbreviations were used for each of these parameters in formulating filenames for the curvefitting process and the spreadsheet tool:

Table 5
Coding for Dispersion Modeling Runs

Parameter	Option	Abbreviation
Meteorological Dataset	Cowtown	CT
	Casa Grande	CG
	Pinal Co. Housing/Eleven Mile Corner	PC
PM_{10} Averaging Period	Annual	A
	Maximum 24-Hour	D
Road Segment Direction	North-south	V (vertical)
	East-west	H (horizontal)
Receptor Row Direction*	Negative under UTM coordinate system	N
	Positive under UTM coordinate system	P

* A negative direction under the UTM coordinate system is either southerly or westerly. A positive direction is either northerly or easterly.

Using this convention, for example, the files used to evaluate maximum 24-hour average impacts at the receptors west of a north-south road in the zone represented by the Eleven Mile Corner meteorological dataset would be designated as the **PCDMV** (**P**inal **C**ounty Housing/**D**ay/**M**inus receptors/**V**ertically-oriented road) input file.

By fitting a curve to the modeling output data, and then installing the equation to that curve in the spreadsheet, the user is allowed to quickly compute air quality impacts within a range of receptors distances from an unpaved road. The curvefitting program identified the equation type and coefficients that, when combined with receptor distance as a variable, would duplicate the output of the CAL3QHCR model with the greatest accuracy. The coefficients, equation types, and correlation coefficients for the best fitting curves for each of the 24 input combinations for which dispersion models were run are displayed in Table 6.

Table 6 **Curvefit Parameters for Each Dispersion Model Output**					
Model Run	Coef. A	Coef. B	Coef. C	Eqn. Type	r^2
Casa Grande Meteorological Database					
CGAMH	1.26E-06	5.97E+02	-0.4201	5	1.0000
CGAMV	1.83E+02	-4.43E+00	-2.34E+01	4	1.0000
CGAPH	1.291E-06	4.433E+02	-0.2252	5	0.9999
CGAPV	154.0	0.9988	-0.6911	3	0.9999
CGDMH	348.3	-4.069E+00	-2.48E+01	4	0.9996
CGDMV	2.98E+02	0.9985	-0.5969	3	0.9986
CGDPH	1.295	1.311E+03	-1.039E+04	2	0.9999
CGDPV	1.600	1.259E+03	-8.38E+03	2	0.9990
Cowtown Meteorological Database					
CTAMH	5.673E+01	-1.197E+00	-1.312E+01	4	0.9999
CTAMV	1.35E+02	0.9982	-0.6213	3	0.9999
CTAPH	168.8	-3.842E+00	-2.277E+01	4	1.0000
CTAPV	6.127E+01	-0.9418	-1.31E+01	4	0.9999
CTDMH	1.415E+00	1.50E+03	-1.23E+04	2	0.9998
CTDMV	1.05E+01	-1.36E-02	8.97E+02	1	0.9989
CTDPH	3.444	1.533E+03	-1.192E+04	2	0.9997
CTDPV	9.572E+00	-1.616E-02	7.64E+02	1	0.9940
Pinal County Housing Meteorological Database					
PCAMH	175.9	0.9987	-0.7417	3	0.9999
PCAMV	129.4	0.9986	-0.6692	3	0.9999
PCAPH	103.7	-1.836E+00	-1.582E+01	4	0.9999
PCAPV	118.3	-1.727E+00	-1.458E+01	4	0.9999
PCDMH	1.705	1.581E+03	-1.399E+04	2	0.9978
PCDMV	0.0000	-1.120E+03	0.3556	5	0.9997
PCDPH	178.8	-1.832E+00	-1.837E+01	4	0.9979
PCDPV	306.0	0.9992	-0.6018	3	0.9999
Equation Types					
1	Linear and Reciprocal: $Y = A + BX + C/X$				
2	Second Order Hyperbola: $Y = A + B/X + C/X^2$				
3	Hoerl Function: $Y = A * B^X * X^C$				
4	Log Normal Equation: $Y = A * e\wedge((\ln X - B)^2/C)$				
5	Cauchy Function: $Y = 1/(A*(X + B)^2 + C)$				

Spreadsheet Tool Design

The spreadsheet tool was designed to be representative, flexible, and fast for use in evaluating the downwind PM_{10} impacts from use of specific unpaved road segments in Pinal County. The users for which the tool was designed are PCAQCD staff who are tasked with recommending unpaved roads for paving by Pinal County Public Works

Department. The tool was designed to provide an objective method for assessing the comparative PM_{10} impacts of unpaved roads on nearby receptors as residential development encroaches near these emission sources.

The spreadsheet tool layout consists of a cover worksheet and several support worksheets. The cover worksheet contains all of the user data entry and program output cells. The user entry data are designed to trigger responses from lookup tables in the support pages and to combine these responses into final answers. These lookup tables include lists of emission factors and unit PM_{10} air quality impacts computed by the curvefitting equations designed to represent the outputs of the CAL3QHCR modeling runs. A separate data entry cell in the cover worksheet asks the user to input the daily traffic count for the unpaved road being studied. The product of the emission factor, the unit air quality impact (at a downwind distance entered by the user), and the daily traffic count are calculated in one of the support worksheets and reported at the right center of the cover worksheet in terms of annual average and maximum 24-hour average PM_{10} impacts at the specified downwind distance from the road.

The supporting worksheets in the spreadsheet model contain calculations of PM_{10} emission factors and unit air quality impacts. The emission factor worksheet uses the silt content, moisture content, and vehicle speed measured on each of the five unpaved roads that were tested in each of the five major soil units to compute PM_{10} emission factors for each road in units of pounds of emission per vehicle mile traveled. When the user selects the major soil unit on the cover worksheet, this worksheet provides the emission factor for that soil type. The air quality impact worksheet computes the annual average and maximum 24-hour averge air quality impacts from a roadway emitting 1.0 gram per second of PM_{10} at the downwind distance entered by the user in the cover worksheet. The unit air quality impacts are then multiplied by the product of the emission factor representing a single vehicle per hour traveling over the unpaved road segment, as converted in units from pounds per mile per day to grams per mile per second, and the daily vehicle count entered by user to produce the air quality impacts at the traffic level and downwind receptor distance entered by the user. These air quality impacts are reported by the spreadsheet at the right center of the cover worksheet. The user can thus observe the changes in estimated air quality impacts that occur as different major soil types, meteorological datasets, roadway orientations, receptor locations, and traffic counts are entered by the user into the cover worksheet.

The user manual for the spreadsheet tool is presented in Attachment A.

Attachment A

User Manual for Spreadsheet Model Used For Computing PM_{10} Impacts from Unpaved Road Travel in Pinal County, Arizona

Introduction

This spreadsheet tool is designed to enable the user to compute the downwind PM_{10} air quality impacts of vehicle travel over unpaved roads in the agricultural district of Pinal County, Arizona. The tool was developed at the request of the Pinal County Air Quality Control District and through funding provided by the Arizona Department of Transportation. The spreadsheet tool was created as an Microsoft Excel file and is designed to be used with version 2000 or higher.

PM_{10} concentrations downwind of an unpaved road are computed in this spreadsheet as the product of several different factors, several of which are entered by the user and others that are preprogrammed into the spreadsheet. Downwind pollutant concentrations are generally dependent upon three factors: the emission factor of the generating source, the activity rate of the source, and the dispersion rate of emissions downwind of the source.

The unpaved road travel emission factor chosen for this spreadsheet is the emission factor equation for light-duty traffic published by EPA in AP-42. This equation uses loose soil silt content, soil moisture content, vehicle speed, and the number of precipitation days per year as variables. The form of the equation, and the constants recommended by AP-42, are reproduced below:

$$E = [(k)(s/12)^a(S/30)^d/(M/0.5)^c - C][(365 - P)/365]$$

where: E = particulate matter emission rate, pound per vehicle miles traveled (lb/VMT)

- k = particulate size factor (dimensionless) = 1.8 for PM_{10}
- s = surface material silt content (%)
- S = mean vehicle speed, miles per hour (mph)
- M = surface material moisture content (%)
- a = empirical constant = 1.0 for PM_{10}
- c = empirical constant = 0.2 for PM_{10}
- d = empirical constant = 0.5 for PM_{10}
- C = PM_{10} emissions from vehicle exhaust, brake wear, and tire wear (lb/VMT)
- P = number of precipitation days per year on which 0.01 inches or more rain falls (days/yr)

The road travel activity rate is entered by the user into the spreadsheet. The units of activity are light-duty vehicles per day passing the midpoint of the road segment of interest. In unpaved road monitoring conducted in June 2005 on five unpaved roads in the agricultural district, daily average vehicle counts ranged from 118 to 644 vehicles per day over a one-week period.

To compute air quality impacts downwind of an unpaved road, the dispersion model CAL3QHCR was run with three locally collected meteorological datasets. The meteorological datasets were collected by PCAQCD at Cowtown (2004), Casa Grande (2004), and Pinal County Housing/Eleven Mile Corner (2003). Model runs were performed for one-mile lengths of unpaved roads running in north-south and east-west directions. The air quality impacts and downwind distances modeled under each meteorological dataset and roadway orientation were then processed through a curvefitting program to develop a mathematical equation that enables a user to interpolate the modeling results between the receptor locations specified in the modeling runs. The receptor locations varied between 25 meters and 500 meters in each direction from the center point of the road segment along a line perpendicular to the roadway centerline. The modeling runs were all conducted at unit PM_{10} emission rates of 1.0 gram per second per road mile.

The air quality impacts computed by the model are the product of the internally calculated emission factor and dispersion factor, and the activity rate entered by the user. The impacts are reported in units of micrograms per cubic meter ($\mu g/m^3$) for both annual average and maximum 24-hour PM_{10} concentrations.

Spreadsheet Use

The spreadsheet tool consists of four worksheets. All user entries should be made in the designated cells in the first worksheet named "DataEntry." The remaining worksheets contain data and calculations that are used in computing the intermediate and final results, which are presented in yellow-highlighted cells in the "DataEntry" worksheet. Descriptions of the data entry sections, and limitations on values to be entered, are described below. Expanded descriptions of the spreadsheet components and development are presented above in the main report.

1. Check the Nearest Meteorological Monitoring Station

In this section of the "DataEntry" worksheet, enter an "x" into the box next to the meteorological monitoring station closest to the road segment being evaluated. The three monitoring stations are shown on the soil map at the bottom of this worksheet. Failure to check one of these boxes, or more than one of these boxes, will cause the spreadsheet to show the error message "#N/A" in the "Calculated PM_{10} Emission Factor" box.

1. Check the Nearest Meteorological Monitoring Station: (enter "x" in one box only)	
Cowtown	x
Casa Grande	
11-Mile Corner	

2. Enter the Major Soil Unit of the Area in Which the Unpaved Road is Located:

The soil map shown on the “DataEntry” worksheet covers the western portion of Pinal County. Five major soil units are found within that portion of this area under agricultural cultivation. The numbers and colors of these major soil units are shown in the legend to the left of the soil map. The soil unit numbers also appear in the larger font on the map itself. Enter the number of the major soil unit in which the unpaved road of interest is located in the box next to “Major Soil Unit No.:”. The entry of a soil unit number not included in the legend will cause the spreadsheet to show the error message “#N/A” in the “Calculated PM_{10} Emission Factor” box. Correct entries in the boxes in sections 1 and 2 will result in the spreadsheet showing values for annual average and maximum 24-hour PM_{10} emission rates in the “Calculated PM_{10} Emission Factor” box. The values and formulas used to calculate these emission factors are contained in the “EmisFctr” worksheet of this spreadsheet.

2. Enter the Major Soil Unit Number of the Area in Which the Unpaved Road is Located:		
Major Soil Unit No.:	1	
Calculated PM10 Emission Factor:		
PM10 Emission Factor =	0.594	lb/VMT - Ann. Avg.
	0.647	lb/VMT - Max. Day

3. Select Orientation of the Unpaved Road:

Within the agricultural district, most unpaved roads run either north-south or east-west. The orientation is important because of the different air quality impacts governed by the prevailing wind directions. In one of the two boxes provided, check the orientation of the road to be evaluated. If the road of concern does not follow one of these two ordinal directions, select the direction that is closest to the orientation of the road centerline. If no orientation direction is selected, or if both boxes are checked, the modeled air quality impact will be reported as “#N/A”.

3. Select Orientation of the Unpaved Road: (enter "x" in one box only)	
North-South	x
East-West	

4. Select Direction of Receptor from Unpaved Road:

For a line source of infinite length with no bends, the air quality impacts will be uniform at all points equidistant from the edge of the source. Thus, the air quality impacts along a line perpendicular to the line source, such as an unpaved road, will represent impacts along any other line that is perpendicular to the road. Because air quality impacts will differ between one side of the road and the other, however, please indicate the direction from the road that the receptor of interest lies. Note that the appropriate alternatives appear in this section of the spreadsheet in response to the centerline orientation of the road selected in section 3 above. Failure to check one of the boxes in this section, or the checking of both boxes, will result in the modeled air quality impact being reported as “#N/A”.

4. Select Direction of Receptor from Unpaved Road: (enter "x" in one box only)	
West	x
East	

5. Enter the Separation Distance Between the Nearest Road Edge and the Receptor:

In order to compute the air quality impact, the separation distance between the receptor and the nearest road edge needs to be identified. Enter this distance in either meters (m) or feet (ft) in the appropriate box. Because the dispersion modeling using CAL3QHCR did not include any receptors that were closer than 25 meters to the road edge, the curvefitting equations will not accurately extrapolate any values for separation distances shorter than 25 meters. The equations will, however, fairly extrapolate air quality impacts at distances greater than 500 meters, the maximum separation distance used in the modeling. If a numerical value of 25 meters, 82.02 feet, or more is not entered into the appropriate box, or if values are entered into both boxes, the modeled air quality impact is reported as "#VALUE".

5. Enter the Separation Distance Between the Nearest Road Edge and the Receptor: (enter value in one box only)		
Separation Distance	25	m
(value cannot be less than 25 m or 83 ft)		ft

6. Enter Number of Vehicles Per Day:

The activity rate in this spreadsheet model is dictated by the number of vehicles per day passing the point on the unpaved road segment closest to the receptor of interest. Enter the daily traffic count in the box. The model assumes an hourly distribution of traffic that is equal to the average recorded on the five unpaved roads tested in the agricultural district in June 2005. Failure to enter the number of vehicles per day will result in the modeled air quality impacts to be reported as "0".

6. Enter Number of Vehicles Per Day:		
Vehicles Per Day:	200	vehicles/day

7. PM_{10} Emission Rates and Air Quality Impacts:

Based on the data entered by the user in sections 1 through 6 of the "DataEntry" worksheet, the spreadsheet model will compute both annual average and maximum daily PM_{10} emissions rates and air quality impacts. The emission factors are reported in units of pounds of PM_{10} emitted per mile of road under the traffic levels specified by the user. The emissions rates for annual and maximum 24-hour averaging periods are different because the annual rate includes the precipitation factor that is not included in the calculation of the maximum 24-hour emission rate. Similarly, the annual average PM_{10} air quality impact is based on the annual average emission rate and the annual meteorological conditions, while the maximum 24-hour average impact is based on the maximum 24-hour emission rate and the meteorological conditions for the worst-case day.

Calculated PM10 Emission Rate:		
PM_{10} Emission Rate =	118.7	lb/mi-day - Ann. Avg.
	129.3	lb/mi-day - Max. Day
Modeled PM_{10} Impact at Receptor Site:		
Annual Impact:	**260.8**	**ug/m3 - Ann. Avg.**
Max. 24-Hr. Impact:	**749.4**	**ug/m3 - Max. Day**

The spreadsheet tool has been locked to prevent accidental modification of the support data or equations. This protection scheme does not require a password, however, to unlock. If the user desires to edit any of the support data, equations, or format of the spreadsheet, simply go to the Tools menu list in Excel, select Protection, and then select Unprotect Sheet to access all portions on an individual worksheet.

The spreadsheet tool has been designed to simply compute the air quality impacts of a single selected scenario of meteorological conditions, major soil type, roadway orientation, and daily traffic count. The resulting cover page can be printed to record the output of each scenario. Boxes are included in the left center of the cover sheet for entering the names of the road being evaluated and the nearest intersecting road. The spreadsheet pages are displayed in Attachment 1 for reference.

Attachment 1

Spreadsheet Tool Worksheets

PM_{10} Air Quality Impact Model - Unpaved Road Travel in the Agricultural District of Pinal County, Arizona

1. Check the Nearest Meteorological Monitoring Station:
(enter "x" in one box only)

Cowtown	x
Casa Grande	
11-Mile Corner	

2. Enter the Major Soil Unit Number of the Area in Which the Unpaved Road is Located:

Major Soil Unit No.: 1

Calculated PM10 Emission Factor:

PM10 Emission Factor = 0.594 lb/VMT - Ann. Avg.
0.647 lb/VMT - Max. Day

3. Select Orientation of the Unpaved Road:
(enter "x" in one box only)

North-South	x
East-West	

4. Select Direction of Receptor from Unpaved Road: (enter "x" in one box only)

West	x
East	

5. Enter the Separation Distance Between the Nearest Road Edge and the Receptor:
(enter value in one box only)

Separation Distance 25 m
(value cannot be less than 25 m or 83 ft) ft

6. Enter Number of Vehicles Per Day:

Vehicles Per Day: 200 vehicles/day

Calculated PM_{10} Emission Rate:

PM_{10} Emission Rate = 118.7 lb/mi-day - Ann. Avg.
129.4 lb/mi-day - Max. Day

Modeled PM_{10} Impact at Receptor Site:

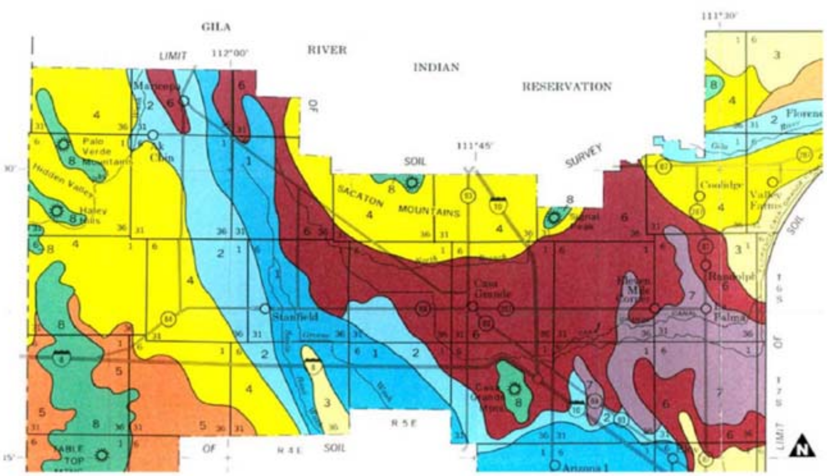
Annual Impact: **260.9 ug/m3 - Ann. Avg.**
Max. 24-Hr. Impact: **749.7 ug/m3 - Max. Day**

Road To Be Evaluated:

Nearest Intersecting Road:

Major Soil Unit Colors and Numbers

=1
=2
=4
=6
=7



Emission Factors

Project: Pinal County Unpaved Roads

Emission Factor

$E = [(k)(s/12)^a(S/30)^d/(M/0.5)^c - C](365 - P)/(365)$

where
- E = size-specific emission factor (lb/VMT)
- s = surface material silt content (%)
- S = mean vehicle speed (mph)
- M = surface material moisture content (%)
- C = emission factor for vehicle fleet exhaust, brake wear, and tire wear (lb/VMT)
- P = number of precipitation per year on which 0.01 in. or more of rain falls (day/yr)
- a = 1 for PM_{10}
- c = 0.2 for PM_{10}
- d = 0.5 for PM_{10}
- k = 1.8 for PM_{10}
- C = 0.00016 lb/VMT
- P = 30 day/yr

Unpaved Road Measurements

Road	Silt Content	Moisture Content	Mean Speed	Soil Area
Alsdorf Road	2.60%	0.097%	42.8	1
Amarillo Valley Road	7.40%	0.270%	40.7	4
Curry Road	4.20%	0.154%	40.5	7
Peters Road	7.10%	0.313%	34.1	2
White & Parker Road	5.90%	0.477%	40.5	6

		PM_{10} Emission Factor, lb/VMT	
Road	Soil Unit	(Ann. Avg.)	(Max. Day)
Alsdorf Road	1	0.594	0.647
Peters Road	2	1.145	1.247
Amarillo Valley Road	4	1.341	1.461
White & Parker Road	6	0.953	1.038
Curry Road	7	0.851	0.927

Curve Fitting Equations

A = annual
D = 24-hr
M = minus, west or south
P = plus, east or north
V = north-south road
H = east-west road

Receptor Distance = 25 meters
Emission Rate = 14.96 gm/sec - Anı
= 16.30 gm/sec - Ma

User-Entered Selections

Facility	Minus/Plus	Vert/Hor
CT	M	V

Model Run	Best Fit Equation	A	B	C	Impact at Receptor Using Unit Emission Rate (ug/m^3)	Impact at Receptor Using Calc. Emission Rate (ug/m^3)
CGAMH	25	1.26E-06	5.97E+02	-0.4201	14.6	218.8
CGAMV	22	1.83E+02	-4.43E+00	-2.34E+01	15.0	224.4
CGAPH	25	1.291E-06	4.433E+02	-0.2252	17.3	258.3
CGAPV	19	154.0	0.9988	-0.6911	16.2	241.7
CGDMH	22	348.3	-4.069E+00	-2.48E+01	40.8	665.7
CGDMV	19	2.98E+02	0.9985	-0.5969	42.1	685.7
CGDPH	7	1.295	1.311E+03	-1.039E+04	37.1	604.9
CGDPV	7	1.600	1.259E+03	-8.38E+03	38.5	628.3
CTAMH	22	5.673E+01	-1.197E+00	-1.312E+01	12.8	192.0
CTAMV	19	1.35E+02	0.9982	-0.6213	17.4	260.9
CTAPH	22	168.8	-3.842E+00	-2.277E+01	18.9	282.7
CTAPV	22	6.127E+01	-0.9418	-1.31E+01	16.3	243.8
CTDMH	7	1.415E+00	1.50E+03	-1.23E+04	41.8	682.1
CTDMV	4	1.05E+01	-1.36E-02	8.97E+02	46.0	749.7
CTDPH	7	3.444	1.533E+03	-1.192E+04	45.7	744.8
CTDPV	4	9.572E+00	-1.616E-02	7.64E+02	39.7	647.4
PCAMH	19	175.9	0.9987	-0.7417	15.6	234.0
PCAMV	19	129.4	0.9986	-0.6692	14.5	216.8
PCAPH	22	103.7	-1.836E+00	-1.582E+01	20.6	308.5
PCAPV	22	118.3	-1.727E+00	-1.458E+01	22.1	330.6
PCDMH	7	1.705	1.581E+03	-1.399E+04	42.6	693.7
PCDMV	25	0.0000	-1.120E+03	0.3556	36.8	599.5
PCDPH	22	178.8	-1.832E+00	-1.837E+01	44.6	726.8
PCDPV	19	306.0	0.9992	-0.6018	43.2	704.6